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FINAL REPORT

STUART A. SCHLEUSENER

JUNE 30, 1980

U.S. ARMY RESEARCH OFFICE

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NEW MEXICO STATE UNIVERSITY

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Electret, subminiature microphone, low-pressure spectrophone, miniature spectrophone

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Subminiature electret microphones were used in miniature spectrophone tests. Data has been obtained from gas mixtures with pressures as high as 660 Torr down to as low as 2 Torr of CO_2. Line broadening effects are very noticeable throughout the lower pressure region. Results show that subminiature electret microphones are competitive with other transducers in spectrophone work.

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INTRODUCTION

Optoacoustic spectroscopy (O-A) can be used to measure very small absorption coefficients in gaseous media. The procedure consists of placing a spectrophone between the source and detector of those electromagnetic wavelengths that more information is required on. The electromagnetic energy is first converted into sound and then into an electrical signal. Use of this concept was first proposed by Alexander Graham Bell [1] in 1880 when he observed that audible sound can be produced by exposing a gas in a transparent, constant-volume container to intensity-modulated infrared radiation. Since then, more refined methods have been introduced by Kruezer [2]; Dewey, Kamm, and Hackutt [3]; and Rosengren [4]. All of these modern systems consist of a cylindrical spectrophone using a phase-sensitive lockin amplifier for detecting the pressure waves created in the spectrophone. The cylinder usually has two apertures, one each for the laser beam entrance and exit. These apertures are normally arranged such that the beam passes lengthwise through the cylinder. The apertures are sealed with windows transparent to the laser wavelengths used.

As the beam passes through the cylinder, it excites the molecules of the test gas to a higher state. When the beam is modulated, the excitation and relaxation of the gas molecules are detected by a microphone placed on the inside wall of the cylinder. This signal is then introduced to a phase-sensitive lockin amplifier using the modulator reference signal as the reference source. The lockin amplifier then extracts the true signal from the cylinder, even from within noise.

Previous research results by Patel and Kerl [5] seemed to indicate that a new small O-A absorption cell system might be useful to the U.S. Army. Older versions had been using an electret thin film foil microphone which gave satisfactory results. However, special care was required in construction to minimize microphonics and in preamplifier usage because of low microphone sensitivity. An additional concern would be encountered in a nonlaboratory environment wherein the foil might be subjected to conditions that could degrade its performance or shorten its useful lifetime.

ELECTRET MICROPHONES

Since transducer performance is one of the critical areas in spectrophone design, it was proposed that the use of miniature electret microphones [5] be further investigated with respect to use in very small O-A systems. These microphones appeared to be highly efficient in converting sound energy into an electrical output signal. While this is important, there are other features that may be important. These are: (1) they do not require a d-c bias and therefore they eliminate much cumbersome and noise-producing circuitry, (2) owing to the use of solid dielectrics and the shallow air gap possible in such systems, they have a substantially higher capacitiance per unit area and therefore can be made much smaller (enables use of smaller O-A cells too), (3) they can be made to respond to very low frequencies, and (4) they can be used at lower pressures and temperatures. The low vibration sensitivity is due to the relatively small mass of the electret-microphone diaphragm. By using microphones in which the electret is bonded to the backplate, even lower vibration sensitivities are achieved.

Although electret transducers have been known for more than 40 years, their application was initially limited due to many physical and environmental problems. Most of these shortcomings were eliminated about 15 years ago by the introduction of the foil-electret transducer. Since then, an increasing number of laboratories throughout the world have become involved in research and development activities in this field. However, most commercial and experimental applications have occurred only over the past ten years. The entire field is presently in a very active phase and a rapid growth in research, development, and practical uses is forseen. A good example of this is that the miniature electret microphones now available are more sensitive by a factor of two or more over those available when the herein test results were obtained.

In detail, an electret is a piece of material which is permanently electrically polarized. The polarization is not affected by an external electric field (except when the external field is strong enough to destroy the electret completely), and this distinguishes the electret from a ferroelectric material (such as barium titanate $BaTiO_3$). Thus, an electret is the electrostatic analogue of a permanent magnet, and gives rise to electric flux lines (and electric fields) external to itself. The analogy is not, however, an exact one because on a microscopic scale there is no free magnetic monopole but there is free electric charge. On the macroscopic scale, a magnet is usually long with small pole faces, while an electret is normally short with large area working faces.

The typical electret material is an organic wax or plastic, a material of poor electrical conductivity. The work-horse material has been carnauba wax (used in floor polishes), but shellac, sealing wax, and naphthalene have been used. Such substances are usually amorphous solids, though some do form single crystals and have been studied in this habit. Current industrial interest lies in the polymer materials such as Mylar and other commercial films. The polymers typically consist of microcrystals embedded in an amorphous matrix, though the crystallin fraction can vary from a few percent to over 90% depending on the particular polymer and its thermal and mechanical history. A fair amount of work has also been devoted to zinc sulphide and other II-VI inorganic materials, normally employed either as pressed powders or in particulate form dispersed in an indifferent binder.

As indicated above, in the 1960's, electret microphones were suggested in which the diaphragm was composed of a metalized thin foil of Mylar or Teflon which had been converted into an electret. One obvious advantage of such transducers over previous electret microphones is the high capacitance due to the small spacing between the electrodes. It was also shown that while Mylar has good mechanical properties, its characteristics as an electret, especially in humid atmospheres, are not satisfactory. Teflon, on the other hand, was found to be excellent as far as its charge-storage properties are concerned and also exhibits satisfactory mechanical characteristics. Even today, Teflon and related materials still appear to have the best properties in terms of charge lifetimes under extreme operating conditions.

By 1968, activity in foil-electret-transducer research and development took on many new fronts: First, electret microphones were evaluated by field test for use in telephony. Then, reliability studies of such microphones were performed at high temperatures and humidities. Finally, in the same year, commercial foil-electret microphones were placed on the market. More recently, an electret microphone with a monolithic integrated-circuit preamplifier was introduced (actually several years ago). A number of this type was purchased for work on this project.

The O-A tests reported on herein utilized subminiature condenser electret microphones with an improved electret film and an integral FET amplifier. These units were the CA 1833 models from Knowles Electronics in Franklin Park, Illinois. Figures 1 and 2 show their physical size and characteristics. A total of 100 were obtained at a unit cost of $6.84 each. Dramatic price increases were quoted for smaller quantities.

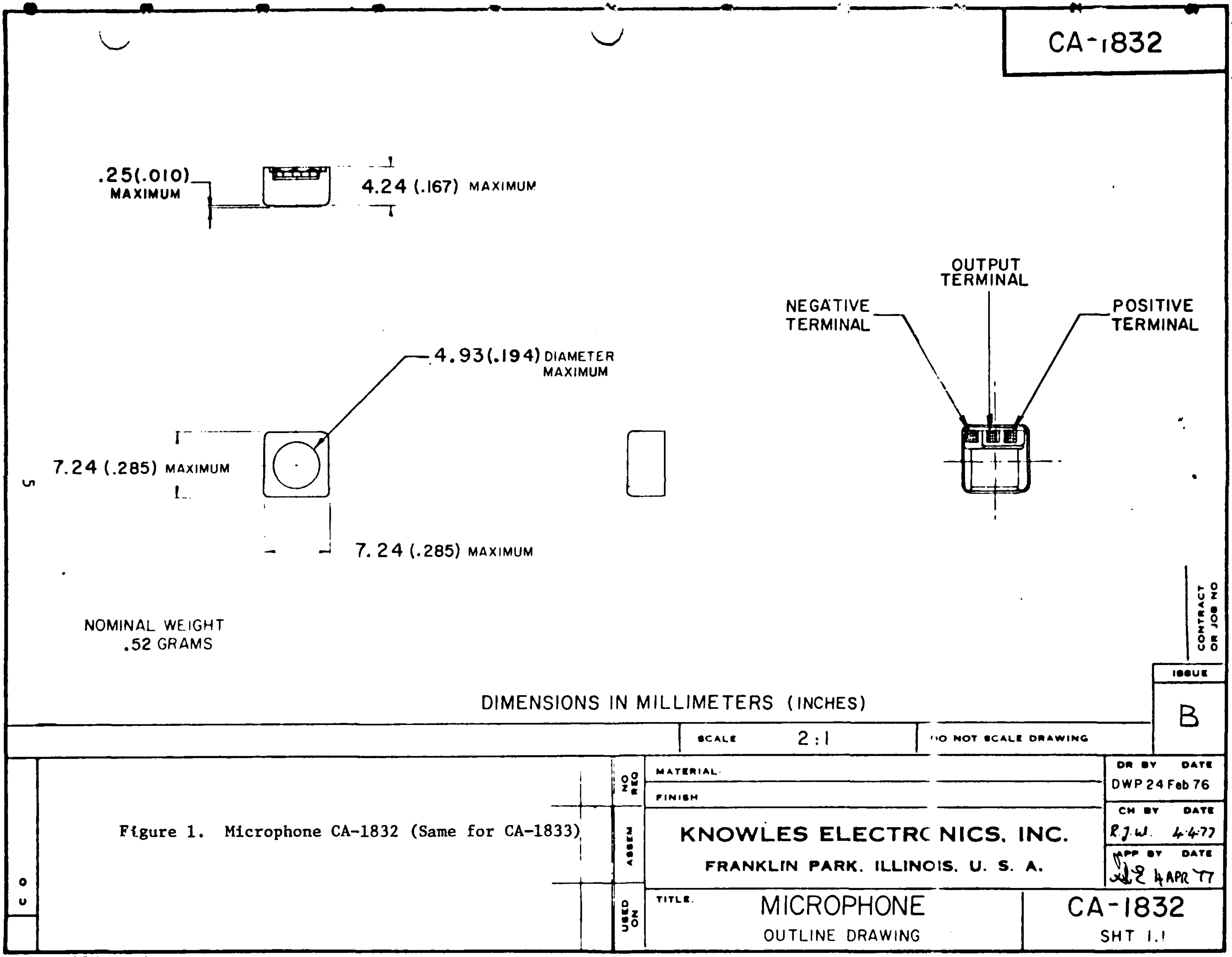
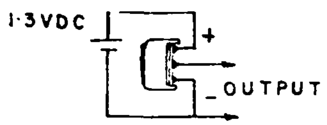
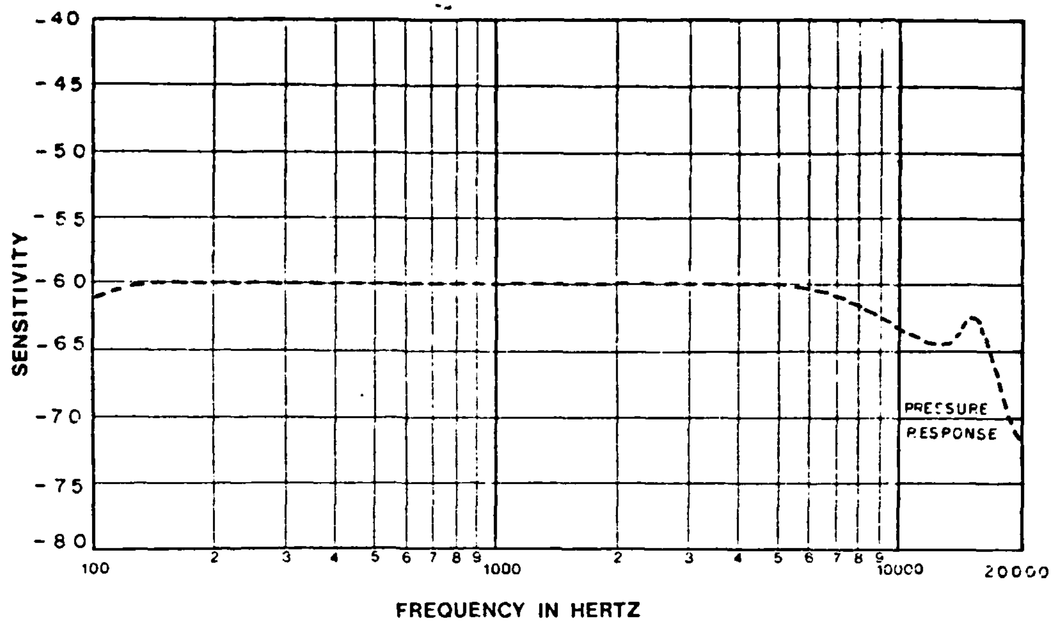


Figure 1. Microphone CA-1832 (Same for CA-1833)

NOTE:

When test limits are used to establish incoming inspection acceptance/rejection criteria, correlation of test equipment with Knowles is also required for elimination of equipment and test method variations





1. OPEN CIRCUIT PRESSURE SENSITIVITY IN dB RELATIVE TO 1.0 VOLT/MICROBAR (0.1 N/m^2).
2. DC SUPPLY: 1.3V.
3. AMPLIFIER CURRENT DRAIN: 100 μA MAX.
4. OUTPUT IMPEDANCE: 2500 OHMS MAX.
5. CASE CONNECTED TO NEGATIVE TERMINAL.
6. "A" WEIGHTED NOISE (1 KHz EQUIVALENT SPL): 31 dB SPL MAX.
7.

	SENSITIVITY			DEVICE CONFORMITY	
FREQUENCY	MIN.	NOM.	MAX.	RANGE OF DEVIATION FROM 1 KHz	
100	---	-61	---	-4	+2
1000	-63	-60	-57	---	---
≈ 15000	---	-63	---	-1	-7

Figure 2. Microphone CA-1832, characteristics (Same for CA-1833).

OPTOACOUSTIC TEST SYSTEM

Figure 3 shows the system layout for the small spectrophone tests. The laser source used is a tunable CW Sylvania Model 950 CO_2 laser operating in the infrared portion of the electromagnetic spectrum at the 10P20 line (10.6 micrometers) with an average power of about 0.5 watts reaching the cell. The modulated beam is passed through the small cell with some radiation being absorbed, depending on the test gas mixture.

The modulator (Ithaco light chopper with adjustable speed control) chops the infrared radiation at a frequency convenient for application to a lockin amplifier. Radiation out of the chopper is approximately half of the incident laser power.

The first rotatable mirror after the chopper is used to reflect the CO_2 beam to a spectrum analyzer (Optical Engineering Inc.). The second rotatable mirror is used for measuring laser power. The beam is deflected into a Scientech Model 36-2002 thermopile detector. A similar detector measures the power out of the cell.

When the rotatable mirrors are out of the beam path, the CO_2 beam passes through a telescope which controls the beam diameter. Care must be taken to ensure that the beam out of the telescope passes cleanly through the cell. The gas mixture to be studied is introduced through copper and flexible tubing.

The output of the electret microphones is filtered by an integrated UAF31 adjustable bandpass filter with a 100-Hz bandwidth and amplified by an inverting amplifier using an LM741 op-amp. The bandpass filter is used to eliminate very high and low frequency noise. The total gain is set at 8800. This roughly filtered signal is then applied to the lockin amplifier.

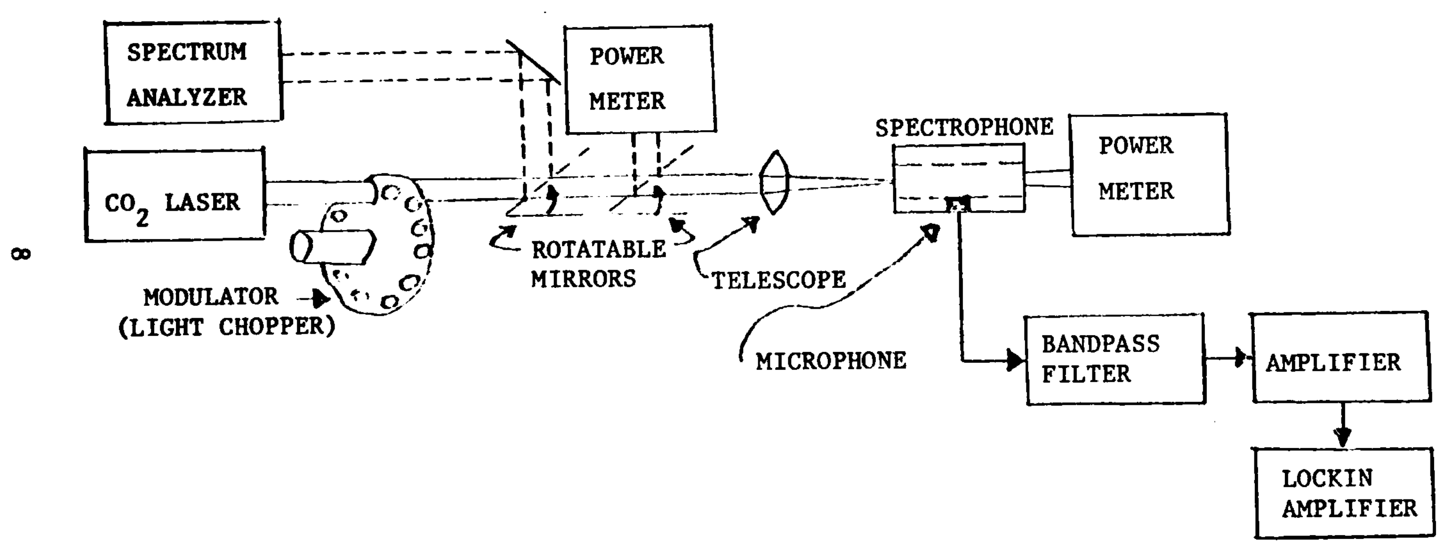


Figure 3. Test system layout for small microphone-spectrophone testing.

Before an experiment can be performed, residual gases in the cell must be removed. In order to do this, the spectrophone cell must be pumped out to near vacuum and flushed several times with N_2. After several N_2 evacuations, introduction of a specific amount of test gas in N_2 may be made. In these experiments, the host gas is N_2 and the gas to be analyzed CO_2. Both the percentage of CO_2 and the total pressures were varied over wide ranges.

Infrared absorption produces excited vibrational-rotational states in the absorbing molecules, and visible and ultraviolet radiation produces excited electronic levels. Collisions between the excited molecules and background gas increase the translational energy and hence the pressure of the sample. The subminiature electret microphone is inserted flush with the wall of the chamber and is used to detect this increase in pressure. The acoustic signal is proportional to the intensity of the incoming radiation and to the concentration of the absorbing species. It is, however, inversely proportional to the volume of the cell. Therefore, the smaller the cell the greater sensitivity per constant path length.

Three small O-A cell systems were constructed for use in testing with the subminiature electret microphones. The largest consisted of a differential unit made up of two 1/2-inch Swagelok B-810-3TTF Female Branch Tee's in series as shown schematically in Fig. 4. Another system consisted of just half the differential system shown in Fig. 4. The last and smallest cell to be mentioned consists of one 1/4-inch Swagelok B-400-3TTF Female Branch Tee. Of course, valves to control the gas mixtures in and out of these cells are as large as the cells themselves in some cases. Therefore, the size of the cells themselves do not necessarily determine the sensitivity of the total system. The valves used for control purposes were NUPRO B-2H2 Bellows Valves with 1/8-Male NPT. Full details on the tee's and valves are

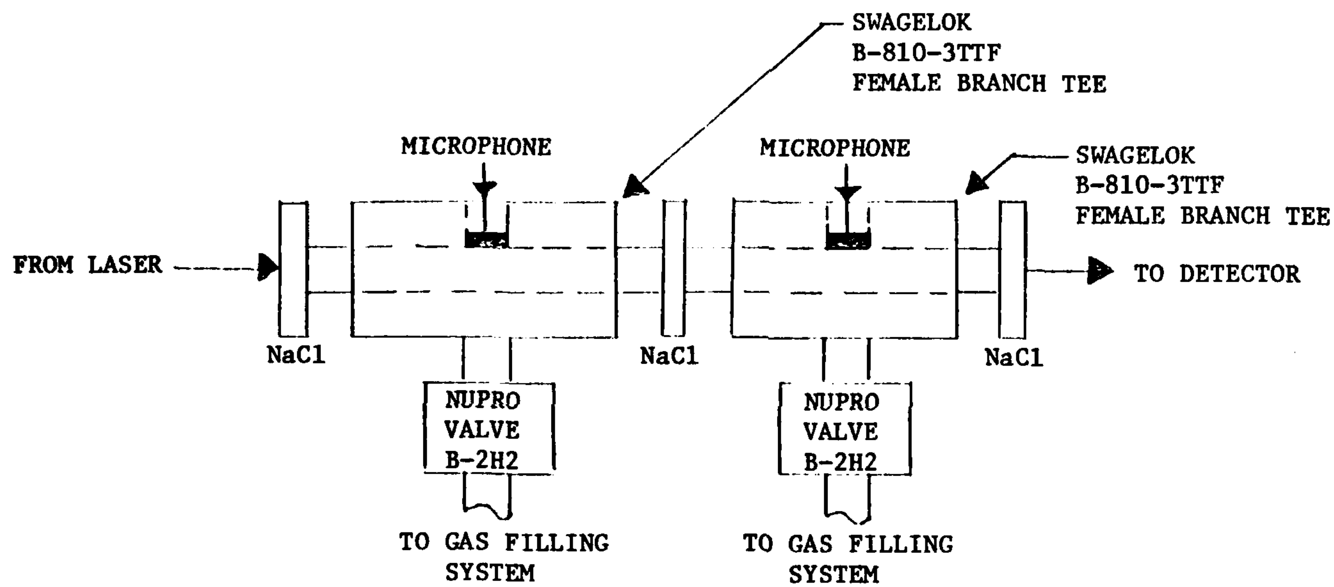


Figure 4. Differential 1/2-inch Swagelok brass tubing tee spectrophone system. Not used in a differential mode.

given in Figs. 5 and 6 respectively.

The decision to use Swagelok components as cells was based on small size, availability, and convenience. Also, the ability to couple directly to controlling valves helped minimize volume and increase sensitivity. Sodium chloride flats were used as aperture windows in all cases. Small holes were bored in the side of the tee's for mounting of the CA1833 electret microphones. Only one microphone per cell was used because of space limitations.

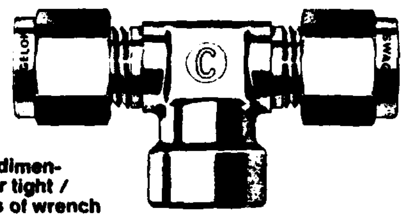
RESULTS AND CONCLUSIONS

Three sets of tests were completed using the above mentioned three systems. Figures 7 and 8 illustrate test results of using a single 1/2-inch Swagelok brass tubing tee as the spectrophone body using CO_2 mixtures as low as 2 Torr. Figure 9 shows test results for a 10-Torr CO_2 mixture in one-half of the differential system and only N_2 in the other while Fig. 10 shows data for the smallest cell of all.

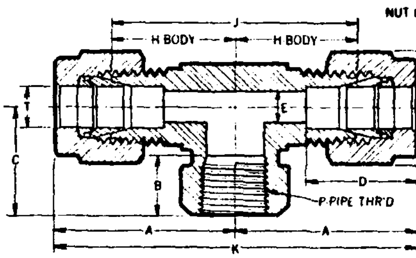
There are a multitude of ways to arrange and compare all of the absorption data obtained. However, it is felt that this is better left to the spectroscopists as far as CO_2 absorption is concerned. The following statements will concentrate more on the small cell-microphone combination itself. Even then, it should be pointed out that the combinations of self-broadening, foreign-broadening, cell pressure response, and microphone pressure response make it nearly impossible to separate out any unique behavior response.

Not all of the proposed work phases were completed. Certainly, the choice and use of Swagelok components for small cell size and geometries seemed quite satisfactory. The connections for windows and valves are very convenient, although the connection of a single valve can nearly double the cell volume. It is hard to see how

FEMALE BRANCH TEE



NOTE—A-D-K dimensions are finger tight / F = across flats of wrench pads / G dimension is across hex flats



T Tube O.D.	P Female Pipe Size	CATALOG NUMBER	A	B	C	D	E Minimum Opening	F	G	H	J	K
1/16	1/16	-100-3TTF	23/32	25/64	3/4	11/32	.052	7/16	5/16	9/16	1 1/8	1 7/16
1/8	1/8	-200-3TTF	31/32	25/64	3/4	17/32	3/32	1/2	7/16	11/16	1 3/8	1 15/16
3/16	1/8	-300-3TTF	1	25/64	3/4	9/16	1/8	1/2	1/2	23/32	1 7/16	2
1/4	1/8	-400-3TTF	1 1/16	25/64	3/4	5/8	3/16	1/2	9/16	3/4	1 1/2	2 1/8
1/4	1/4	-400-3-4TTF	1 3/16	19/32	27/32	5/8	3/16	11/16	9/16	7/8	1 3/4	2 3/8
5/16	1/8	-500-3TTF	1 1/8	25/64	3/4	21/32	1/4	1/2	5/8	13/16	1 5/8	2 1/4
3/8	1/4	-600-3TTF	1 1/4	19/32	27/32	11/16	9/32	11/16	11/16	15/16	1 7/8	2 1/2
1/2	3/8	-810-3TTF	1 7/16	19/32	29/32	29/32	13/32	13/16	7/8	1 1/32	2 1/16	2 7/8
1/2	1/4	-810-3-4TTF	1 3/8	19/32	29/32	29/32	13/32	11/16	7/8	31/32	1 15/16	2 3/4
1/2	1/2	-810-3-8TTF	1 17/32	25/32	1 1/16	29/32	13/32	1	7/8	1 1/8	2 1/4	3 1/16
5/8	1/2	-1010-3TTF	1 17/32	25/32	1 1/8	31/32	1/2	1	1	1 1/8	2 1/4	3 1/16
3/4	3/4	-1210-3TTF	1 21/32	25/32	1 1/4	31/32	5/8	1 1/4	1 1/8	1 1/4	2 1/2	3 5/16
7/8	3/4	-1410-3TTF	1 11/16	25/32	1 1/4	1 1/32	23/32	1 1/4	1 1/4	1 9/32	2 9/16	3 3/8
1	1	-1610-3TTF	1 31/32	1	1 1/2	1 7/32	7/8	1 11/16	1 1/2	1 1/2	3	3 15/16
1	3/4	-1610-3-12TTF	1 25/32	25/32	1 1/4	1 7/32	7/8	1 1/4	1 1/2	1 5/16	2 5/8	3 9/16

All dimensions in inches. Dimensions for reference only . . . subject to change

CRAWFORD FITTING COMPANY / 29500 SOLON ROAD / SOLON, OHIO 44139

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Figure 5. Swagelok Female Branch Tee.

NUPRO®
"H" SERIES BELLOWS VALVES

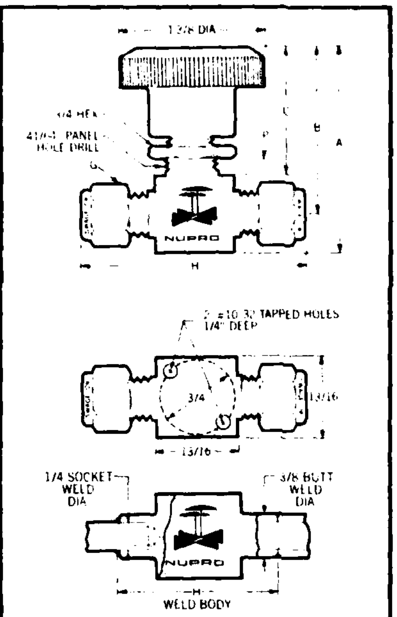
MATERIALS

[illegible]	BRASS	STAINLESS STEEL
Stem	Silicon bronze with TFE coated stem tip	316L stainless steel
Stem Insert	N/A	Hardened 17-4PH stainless steel
Bellows	Phosphor bronze (seamless)	321 stainless steel (seamless)
Retaining Ring	Beryllium copper	15-7-MO stainless steel
Ring	Phosphor bronze	316 stainless steel
Spring	302 stainless steel	17-7PH high tensile stainless steel
Body, Bonnet	Brass	316L stainless steel
Solder (body to bonnet joint)	Tin-silver eutectic	N/A
Pin	N/A	420 stainless steel (passivated)
Cap	Hunter Green phenolic plastic	Aluminum, anodized Hunter Green
All Other Parts	Brass	316 stainless steel

TABLE OF DIMENSIONS

"H" SERIES VALVES		CONNECTION SIZE	DIMENSIONS②						
PART NUMBER	PORT① ORIFICE (INCHES)	INLET AND OUTLET	A OPEN	A CLOSED	B OPEN	C OPEN	G HEX	H	P MAX.
B-2H	0.082	⅛ SWAGELOK	2 3/32	2 3/64	1 11/16	1 9/32	7/16	2⅛	3/16
B-2H2	0.125	⅛ Male NPT	2 3/32	2 3/64	1 11/16	1 9/32	—	1 9/16	3/16
B-2H4	0.156	⅛ Female NPT	2 3/32	2 3/64	1 11/16	1 9/32	—	1¾	3/16
B-4H	0.156	¼ SWAGELOK	2 3/32	2 3/64	1 11/16	1 9/32	9/16	2 5/16	3/16
B-4H2	0.156	¼ Male NPT	2 3/32	2 3/64	1 11/16	1 9/32	—	1 15/16	3/16
B-4H4	0.156	¼ Female NPT	2 3/32	2 3/64	1 11/16	1 9/32	—	1 15/16	3/16
SS-2H	0.082	⅛ SWAGELOK	2 13/32	2 23/64	2	1 19/32	7/16	2⅛	11/32
SS-2H2	0.125	⅛ Male NPT	2 13/32	2 23/64	2	1 19/32	—	1 9/16	11/32
SS-4H	0.156	¼ SWAGELOK	2 13/32	2 23/64	2	1 19/32	9/16	2 5/16	11/32
SS-4H2	0.156	¼ Male NPT	2 13/32	2 23/64	2	1 19/32	—	1 15/16	11/32
SS-4H4	0.156	¼ Female NPT	2 13/32	2 23/64	2	1 19/32	—	1 15/16	11/32
③SS-4H-TSW	0.156	¼TSW / ⅜MTW	2 13/32	2 23/64	2	1 19/32	—	1½	11/32
B-(6MM) H	3.97MM	6MM SWAGELOK	2 3/32	2 3/64	1 11/16	1 9/32	9/16	2 5/16	3/16
SS-(6MM) H	3.97MM	6MM SWAGELOK	2 13/32	2 23/64	2	1 19/32	9/16	2 5/16	11/32

① Port orifice determines maximum flow.
② Dimensions shown with SWAGELOK nuts finger-tight, when applicable.
③ Factory welded tube extensions can be supplied. (See page 5)



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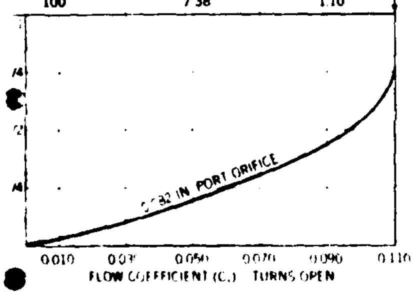
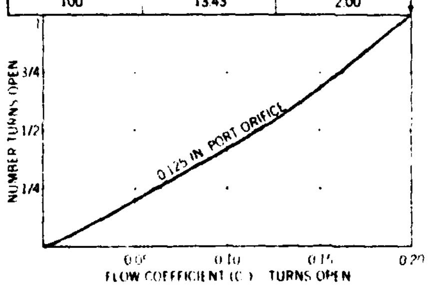
FLOW CAPACITY CURVES

Figure 6. Nupro "H" Series Bellows Valves.

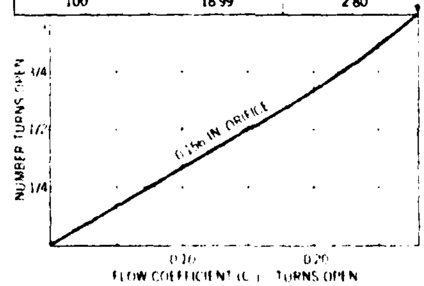
[illegible]		
[illegible]	[illegible]	[illegible]
10	1.61	0.35
50	4.17	0.78
100	7.38	1.10



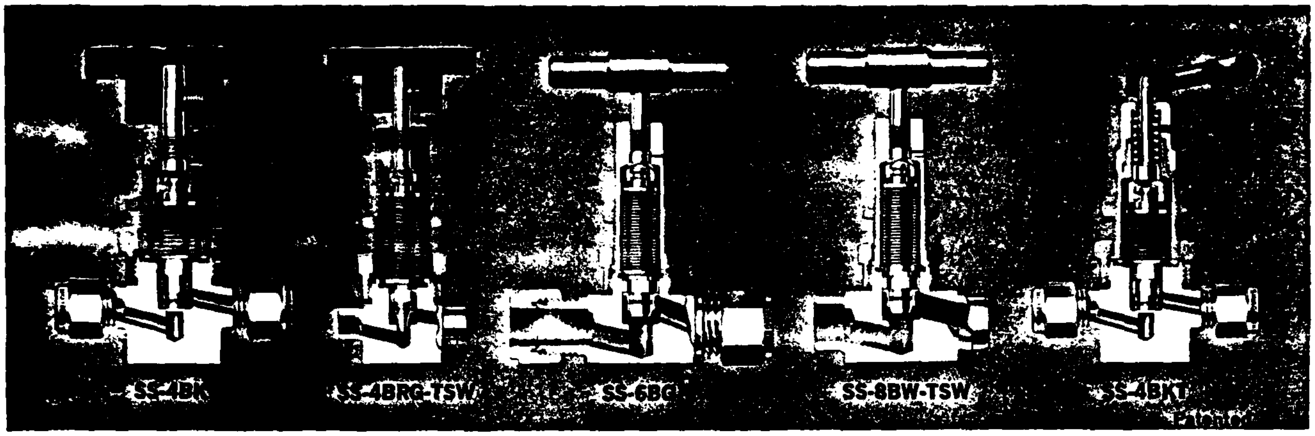
MAXIMUM FLOW FOR C_v = 0.20		
PRESSURE DROP TO ATMOSPHERE (ΔP) PSI	AIR SCFM @ 70°F	WATER GPM @ 70°F
10	2.73	0.63
50	7.57	1.41
100	13.43	2.00



MAXIMUM FLOW FOR C_v = 0.28		
PRESSURE DROP TO ATMOSPHERE (ΔP) PSI	AIR SCFM @ 70°F	WATER GPM @ 70°F
10	3.88	0.89
50	10.71	1.98
100	18.99	2.80



NUPRO®
"B" SERIES BELLOWS VALVES



PURPOSE

NUPRO "B" Series Bellows Valves are versatile general purpose valves, adaptable to a wide range of difficult fluid handling problems. The bellows design eliminates sliding seals and offers greater reliability. Available in 316 stainless steel, Monel or brass with a variety of SWAGELOK or weld connections. A large choice of models, stem types and flow capacities offer great system flexibility.

OPERATION

8 Approximately two turns of the handle opens the NUPRO "4B" Series Bellows Valve to full flow, while the "4BR", "6B" and "8B" Series valves require about four turns. Quick valve actuation is achieved in the "4BKT" Series Toggle Operated Bellows Valve by lifting the handle vertically to open. Instant closure of the valve results when the toggle handle is "flipped" in the opposite direction.

APPLICATIONS

Regulating, shut-off and control of toxic, hazardous, corrosive or expensive fluids • High pressures • Vacuum systems, where bake-out temperatures are reached • Rare or high purity gases • Sampling systems and gas analysis • Cryogenic to high temperature • Vacuum to high pressure • Laboratories • Power plants • Aircraft industries • Ocean systems • Experimental and research facilities • Wherever the most difficult fluid containment problems are encountered.

SPECIAL FEATURES

The "BK" Series is a general purpose, soft seat bellows valve for repetitive shut-off service, featuring a replaceable bellows and stem assembly using a Kel-F gasket and stem insert. The Kel-F insert in all valves is supported over its entire length by a replaceable metal stem adapter. The soft seat design is excellent on vacuum work or pressurized systems where dead tight shut-off must be maintained.

The "BR" Series Bellows Regulating Valves are designed to broaden the flow control range of bellows sealed valves. Having a 0.172" orifice, these valves offer high flow capacity with excellent control and may be used for shut-off service. Gasketed models ("BRG") are available with replaceable bellows and stem assemblies using a metal stem insert and a precision metal O-Ring. Valves are available in 316 stainless steel, brass or Monel. All welded models ("BRW"), available in 316 stainless steel or Monel, are recommended for severe service applications where high temperatures are encountered.

The **"BG" Series** is a bellows valve with a replaceable bellows and stem assembly featuring a metal stem or stem insert. A precision metal O-Ring seals the bellows and stem assembly to the valve body. The "BG" Series, with its all metal construction, is recommended for higher temperatures or applications where plastics cannot be used.

The **"BW" Series** is an all welded, hermetically sealed valve using a metal stem or stem insert. The bellows and stem assembly are not replaceable. The all welded design is excellent for temperature cycling applications. Stellite or 17-4PH stem inserts are available to extend the temperature range of "BW" Series valves beyond that of soft tip or gasketed models.

"BKT" Series Toggle Operated Bellows Valves provide quick, positive, soft seat shut-off in vacuum or pressurized systems. They feature replaceable bellows and stem assemblies with soft Kel-F stem insert and gasket.

NUPRO Toggle Operated Bellows Valves cannot be damaged by heavy handed operators. Swivel joint design allows handle to be rotated to any desired position without damaging the bellows or Kel-F stem insert. Colored handles are available for easy coding of panels.

Additional Features—Positive stem retraction is insured by the actuator/stem joint design on all NUPRO "B" Series Bellows Valves. Some bellows valves tend to stick shut because of the fluids and temperatures encountered in extremely clean systems. In NUPRO "B" Series Bellows Valves, the pin engages a shoulder on the stem and lifts it free if sticking occurs • Safety back seat sealing is accomplished by turning the valve handle to the fully open position. This prevents the escape of fluid in the event of a bellows rupture. The back seating is below the helium test port • 100% helium leak tested • Union bonnet design • Panel and bottom mounting • Low operating torque • Protected threads • Heli-arc welded • Non-rotating stem • On special order a variety of stem inserts can be supplied: copper, hardened 17-4PH and Stellite #6B are available • 316 stainless steel, brass and Monel construction • Angle pattern models also available.

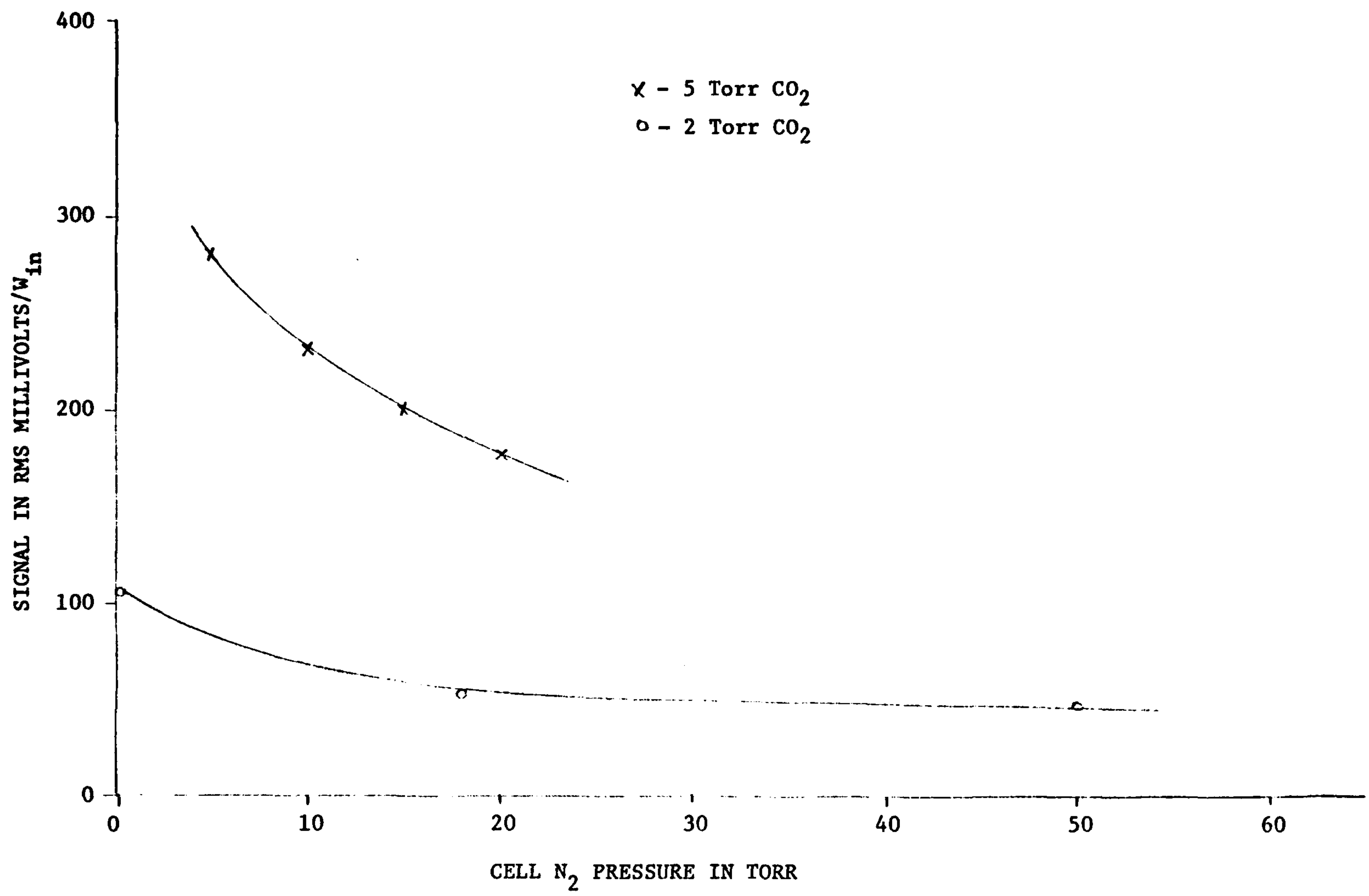


Figure 7. Response of 1/2-inch Swagelok brass tubing tee cell at low pressures.

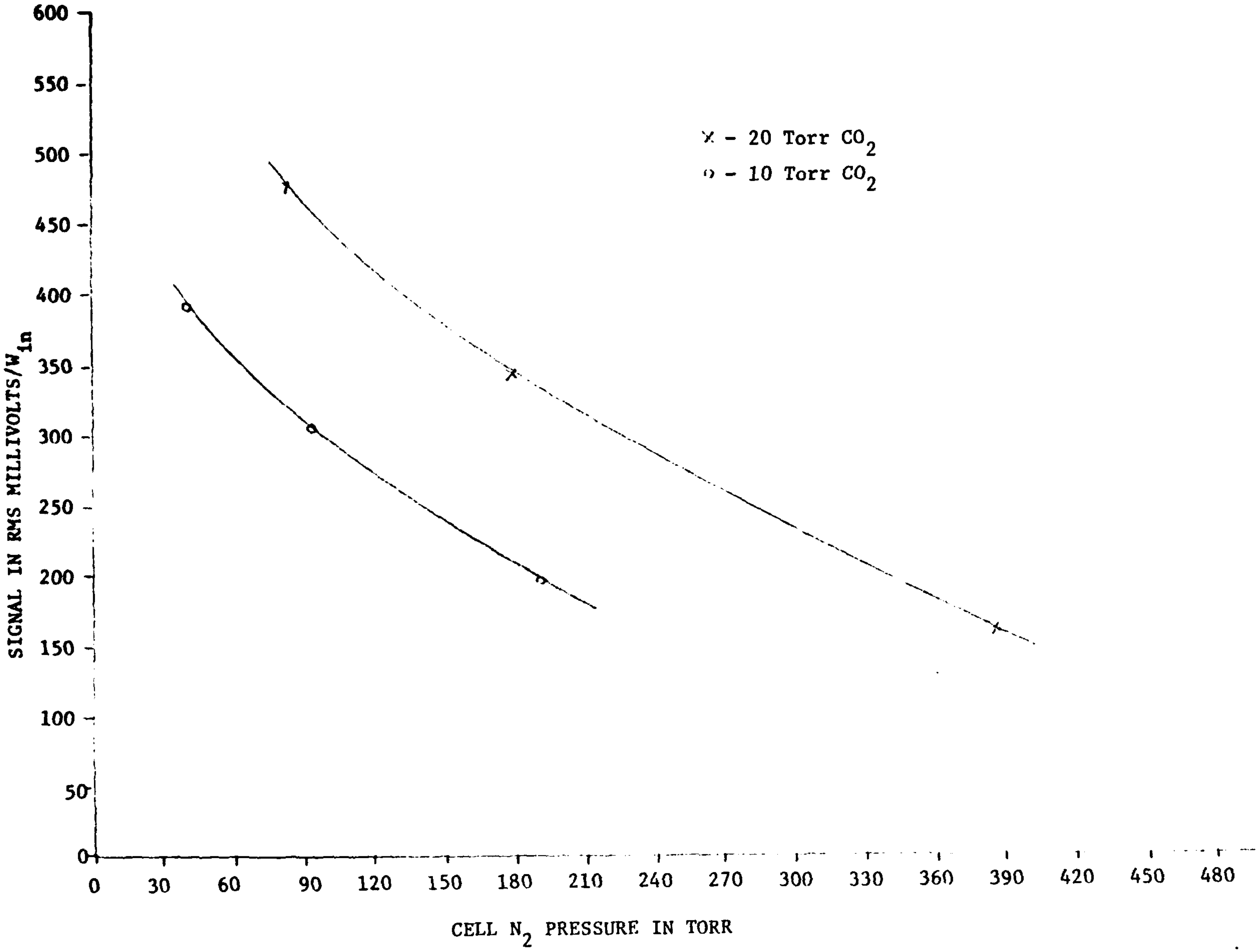


Figure 8. Response of 1/2-inch Swagelok brass tubing tee cell at higher pressures.

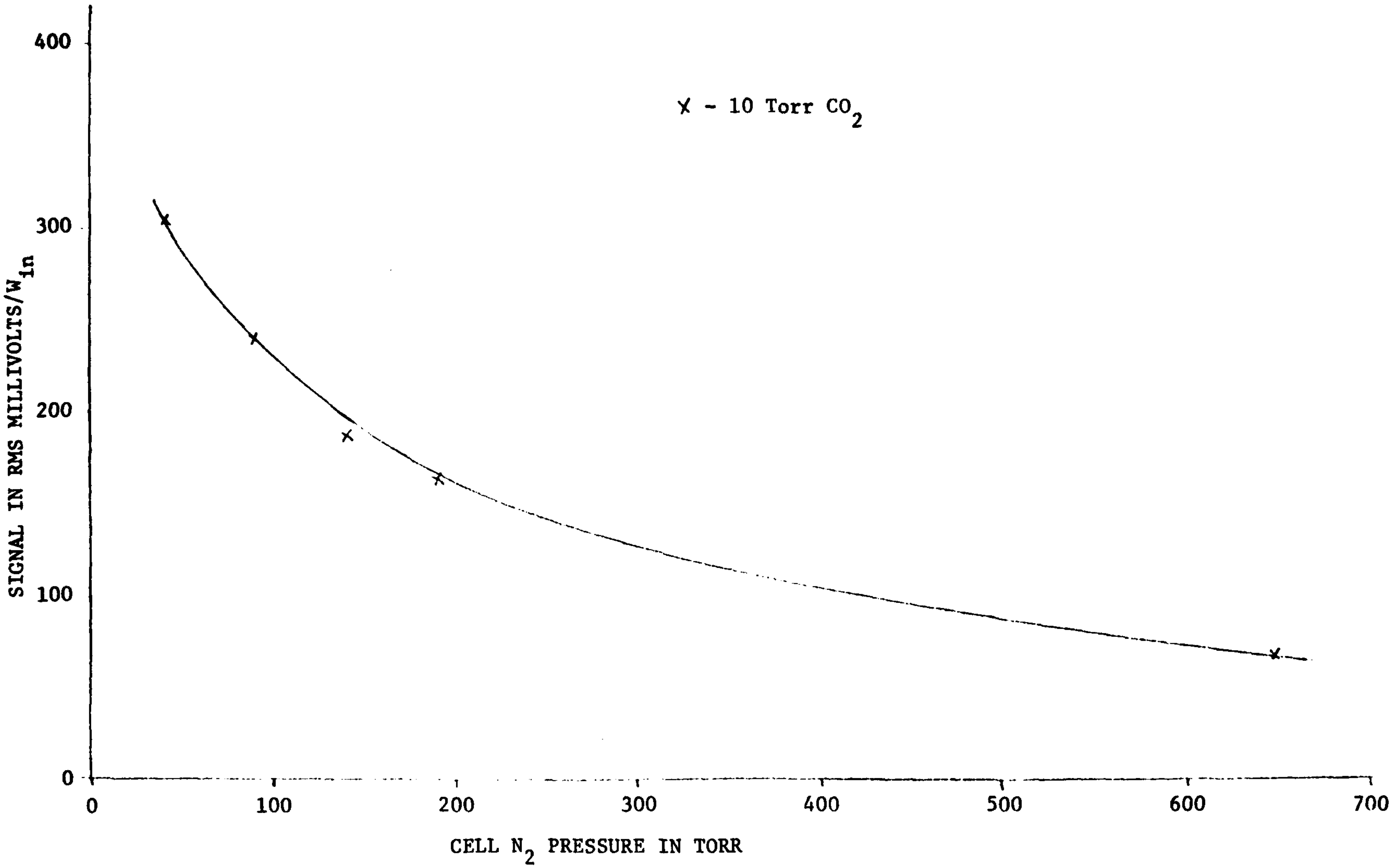


Figure 9. Response of two 1/2-inch Swagelok brass tubing tee cells connected in series. Not used in a differential mode.

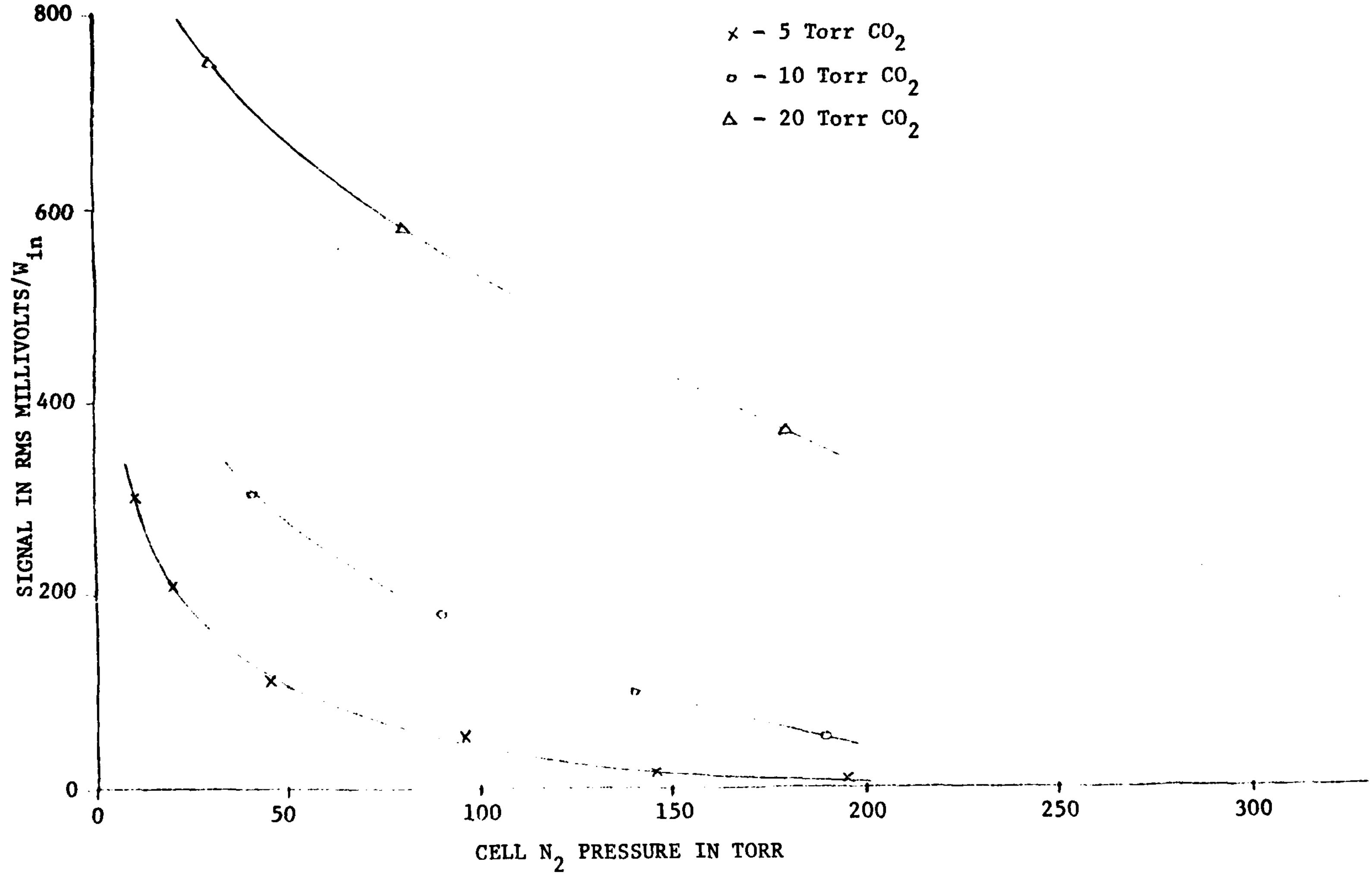


Figure 10. Response of modified Swagelok 1/4-inch brass tubing tee cell.

this could be avoided. The modified (cut-shorter) 1/4-inch unit is as small as one would choose. It did result in slightly greater sensitivity as indicated in Fig. 10. Resonance effects were searched for and little effect was noted, perhaps because of the Swagelok component geometries.

Due to the small cell sizes, only one microphone per unit was used because of space and wall area limitations. In some closely related work, multiple microphone use did not result in a greater signal-to-noise ratio unless physical placement was pertinent because of resonant mode effects.

Low pressure performance was somewhat surprising as noted in Fig. 7. The test using 2-Torr CO_2 and no N_2 still results in substantial signal. So low pressure performance would appear to be excellent for these microphones. Of course, lack of broadening could give rise to strong absorption. A quantitative check on low pressure performance would have to be based on a calibrated cell and use of known gaseous absorption data at very low pressures. No low temperature tests were attempted during this phase. Cell design would be much more complex and would take considerable more time and effort. This work should be done in the future.

As noted in Fig. 9, the data was taken using a differential geometry. However, proper differential usage would have required substantial more effort in design and construction of signal processing electronics. Sufficient data was taken to give indications that differential usage could be feasible and useful in cancelling out some of the noise signal components. However, this should be worked on as a separate project alone. Proper antireflection coating would have to be used on all windows to avoid unwanted reflections and possible etalon resonances at some wavelengths.

In conclusion, it can be stated that the electret microphones performed well in the tests that were completed. The results are definitive enough to warrant substantial future further investigation for usage at low pressures and unusual environmental conditions. A direct outgrowth of this investigation has been the most recent work at ASL/WSMR using a twice as sensitive electret microphone unit as the CA1833 series used herein. Their initial results show that these small microphones are more than competitive for almost all spectrophone usage, including large and small geometries and usual and unusual applications.

Future work should be directed at using more sensitive recently available microphones in both resonant and nonresonant geometries and extensive differential testing. Differential testing requires substantial effort but could pay off in obtaining just that last needed sensitivity for some possible important applications.

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